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Robert S. Kerr Water Research Center
Ada, Oklahoma

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PHOSPHATE REMOVAL AT FORT WORTH, TEXAS

By

J. A. Horn, B. L. DePrater, and J. L. Witherow*

High phosphorus removal from municipal sewage by the activated sludge process was demonstrated by plant monitoring conducted at the Fort Worth Village Creek Water Pollution Control Center. The levels of removal through the plant with emphasis on the activated sludge process are reported herein along with a description of plant design, operation, and flow detention. These parameters are compared with previous phosphate removal data on the Rilling Plant in San Antonio, Texas. (1)(2)

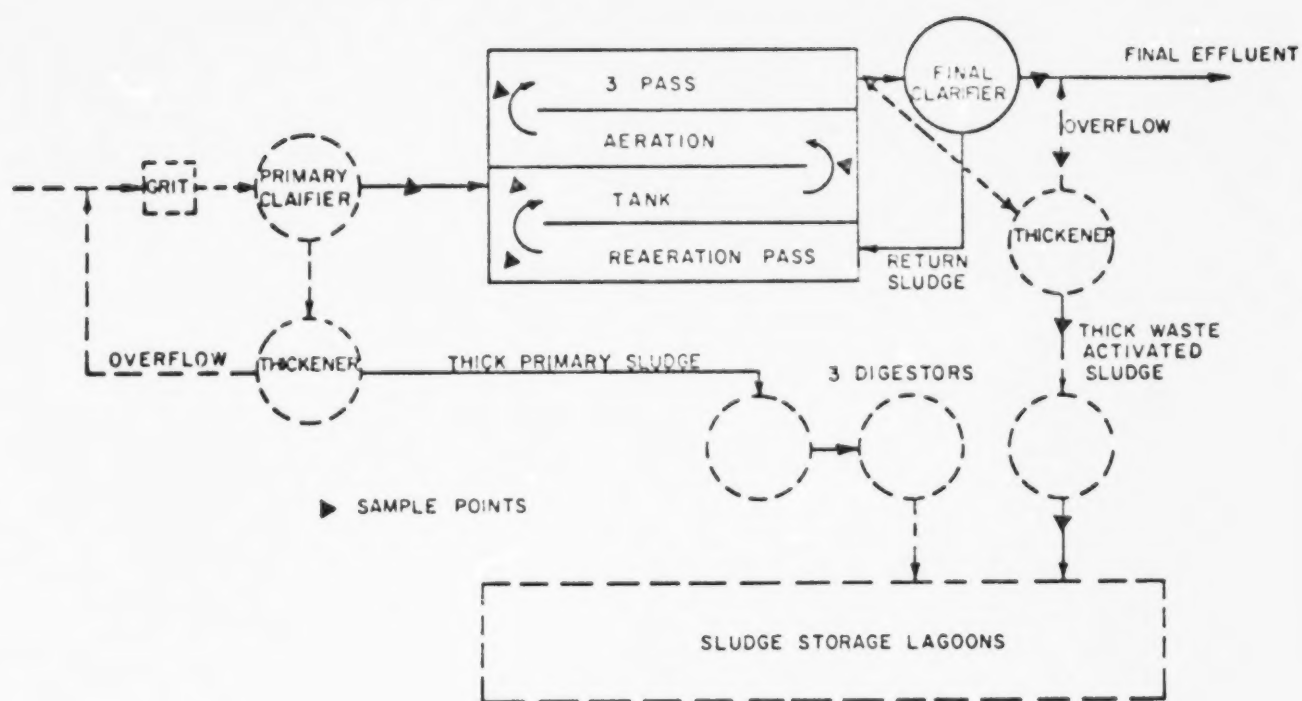
Plant Design

The Village Creek Water Pollution Control Center is a conventional activated sludge plant designed for 30 mgd, 210 mg/l total suspended solids (TSS), and 265 mg/l biochemical oxygen demand (BOD). The major units are described in Table 1, and a schematic drawing of the plant is shown in Figure 1. Present operation utilizes the first pass of each aeration tank for sludge reaeration and the No. 1 final clarifier as a thickener for waste activated sludge. The sewage flows by gravity through the grit removal and primary settling basins and is pumped to the aeration tanks where it flows through the remaining units by gravity. Flow meters monitor the inputs (settled sewage, return sludge, and air) to the aeration tanks.

The major mechanical items are: two fixed speed and two variable speed return sludge pumps with a total capacity of 30 mgd and five single speed and two dual speed blowers with a maximum capacity of 77 MCFD. About 45 MCFD can be developed by three digester or natural gas driven blowers; the others use electrical power.

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VILLAGE CREEK PLANT
ACTIVATED SLUDGE

FIGURE 1

TABLE 1--VILLAGE CREEK WATER POLLUTION CONTROL CENTER'S FACILITIES

<u>Units</u>	<u>No.</u>	<u>Dimensions (ft.)</u>	<u>Design Parameters</u>
Grit Basins	1	26 x 26	10 mgd
	1	35 x 35	20 mgd
Primary Clarifiers	2	80 dia. x 6.5 SWD*	1,000 gal/day/sq. ft. 11,750 gal/day/ft. of weir
	4	80 dia. x 7 SWD*	1,000 gal/day/sq. ft. 20,000 gal/day/ft. of weir
Aeration Tanks	3	30 x 250 x 15 D	4-pass .35 lb. BOD/lb. MLSS/day
Final Clarifiers	5	95 dia. x 10 SWD*	880 gal/day/sq. ft. 13,250 gal/day/ft. of weir
Sludge Thickeners			
Primary	1	65 dia. x 10 SWD*	
Waste Activated	1	85 dia. x 9 SWD*	Converted Final Clarifier
Digesters			
Primary	4	90 dia. x 27 SWD*	2.4 cu. ft./capita
Secondary	2	30 dia. x 21 SWD*	.83 cu. ft./capita
Sludge Storage			
Lagoons	8	--	16 acres--3 yr. use cycle

*Side Water Depth

Plant Operation

Sewage flow to the Village Creek Plant was equalized by using the 10-million gallon holding capacity of 96-inch intake sewer. Humidity within this sewer is controlled by the use of venturi-type ventilators spaced at 1,000-foot intervals. The diurnal flow variation amounted to ± 10 percent, but the diurnal fluctuation in BOD ranged from 150 to 340 mg/l during a 24-hour profile of the primary effluent.

Plant operating and performance data for the study period, November 28 through December 4, 1967, are summarized in Table 2. The analyses were conducted on 24-hour composite samples by plant personnel.

TABLE 2--FORT WORTH VILLAGE CREEK PLANT ACTIVATED SLUDGE
OPERATING DATA

<u>Item</u>	<u>Units</u>	<u>Mean</u>	<u>Min</u>	<u>Max</u>
Primary Effluent: Flow	mgd	25	22	28
BOD	mg/l	260	180	380
Final Effluent BOD	mg/l	17	6	41
Return Sludge: Flow	mgd	7.3	6.4	8.3
Return Sludge: Suspended Solids	mg/l	9,380	8,470	10,200
Air Supplied	ft ³ /gal.	1.5	1.3	1.7
	ft ³ /lb. BOD Rem.	750	510	960
MLSS	mg/l	2,480	2,380	2,630
SVI	ml/g	258	176	322
BOD Loading	lb./lb. MLSS/Day	.35	.23	.49
BOD Removal	%	93	84	97

Previous records indicated the return sludge flow was varied to maintain a BOD load of 0.35 pound per day per pound of activated sludge solids in the aeration basin. During the study period, the plant was operated normally; that is, to obtain maximum removal of BOD and TSS, BOD loading averaged 0.35 and varied from 0.23 to 0.49 lb./day/lb. MLSS. Return sludge flow averaged 29 percent and had a sludge age of 12 days.

The waste activated sludge is concentrated in a thickener and pumped to a separated digester. The supernatant from the thickener is discharged in the final effluent. The discharges from the digester are disposed of in sludge lagoons.

Plant Monitoring

Total phosphate concentrations were determined on composite samples for the seven-day period, November 28 through December 4, 1967, and found to be 17.3, 11.1, and 2.9 mg/l as P in the raw sewage, primary effluent, and final effluent, respectively. During this period, 175 million gallons of sewage was treated. The removal of total phosphate in the primary clarifiers averaged 1,300 pounds per day or 36 percent removal. Total phosphate removal in the activated sludge plant averaged 1,700 pounds per day or 74 percent removal. Overall total phosphate removal from raw sewage to final effluent averaged 84 percent.

The concentrated activated sludge being wasted to the digesters had an average total phosphate content of 1,300 mg/l as P or 7 percent phosphorus on a dry weight basis. The average wasting rate was 200,000 gal/day.

A total phosphate materials balance was computed for the secondary system during the study period. The contents of the aeration tanks were sampled at the beginning and end of the balance period in order to determine how much phosphate had accumulated in the 7.5 mg mixed liquor aeration and 2.5 mg sludge reaeration inventories. Composite samples of the waste activated sludge were taken daily and analyzed for total phosphate. Table 3 summarizes the results.

TABLE 3--FORT WORTH VILLAGE CREEK PLANT TOTAL PHOSPHATE
MATERIALS BALANCE

Input

T-PO₄ in Primary Effluent 16,230 lbs.

Output

T-PO₄ in Final Effluent 4,240

T-PO₄ in Waste Sludge 15,200

Total Output 19,440

Increase in System Inventory (23,800-21,700) 2,100

Total Output + Change in Inventory 21,540

Unaccounted T-PO₄ 5,310

The balance illustrates that the waste activated sludge was the vehicle for removing total phosphate from the system since the increase in the system inventory amounted to only 18 percent of the amount removed from the primary effluent. The 33 percent of unaccounted phosphate was higher than anticipated; however, a part of the error was attributed to estimating waste sludge flow from a pump capacity and elapsed pumping times.

The orthophosphate concentrations of the effluents from the primary clarifiers, aeration tanks, and final clarifiers were determined by analyzing 67 grab samples taken over a 60-hour period. Samples were staggered in proportion to the displacement time of the treatment unit. The summarized data are presented in Table 4.

TABLE 4--EFFLUENT ORTHOPHOSPHATE (mg/l as P)

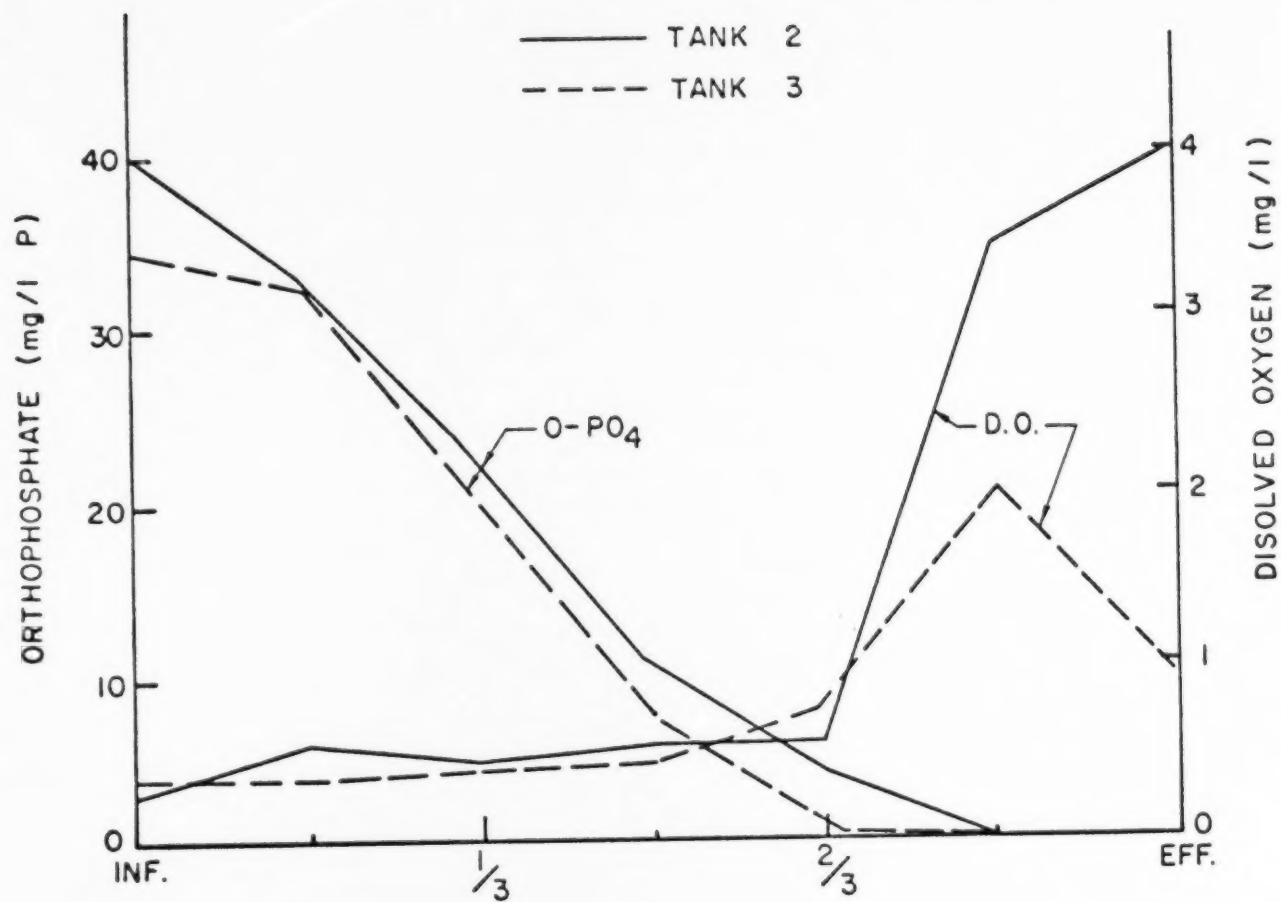
	<u>Primary Clarifiers</u>	<u>Aeration Tanks</u>	<u>Final Clarifiers</u>
Mean	6.5	0.1	1.5
Range	3.8 - 9.5	.03 - .48	.3 - 3.4

Removal in the aeration tanks was 98 percent of the orthophosphate in the primary effluent; however, the concentration increased in the final clarifiers. Overall removal through the activated sludge process was 77 percent.

Because removal occurs in the aeration tanks, additional orthophosphate and dissolved oxygen concentrations of the mixed liquor were determined at the influent, one-third, two-thirds, and effluent points. Time between sampling these points was in proportion to detention. Orthophosphate concentrations were determined on 60 mixed liquor samples, and 40 dissolved oxygen measurements were made in the aeration tank in four separate investigations during the 60-hour monitoring period. In addition, nine samples of reaerated return sludge and four samples of primary effluent were taken at a point just prior to their mixing and analyzed for orthophosphate. A summary of the data collected are shown in Table 5.

In all tanks monitored, the orthophosphate was reduced to less than 0.5 mg/l in the effluent; and, in most cases, the reduction was complete by the two-thirds point (end of the second pass). The dissolved oxygen concentration of the mixed liquor increased through the tank and, in all cases, equaled or exceeded 1.5 mg/l in the third pass of the tank.

Typical change in these two parameters is shown for Aeration Tank Nos. 2 and 3 in Figure 2. The orthophosphate concentrations of the primary effluent and return sludges entering Tank Nos. 2 and 3 were 5.6, 37.0, and 51.0 mg/l, respectively. The computed concentration of the mixed liquor was 15.0 mg/l in Tank No. 2 and 19.2 mg/l in Tank No. 3, but the measured concentrations were considerably greater at 40.2 and 34.9 mg/l. The increase is attributed to a release of phosphate from the return sludge solids to the liquid upon mixing.



LOCATION IN AERATION TANK

FIGURE 2

TABLE 5--AERATION TANK MONITORING

	Inputs		Mixed Liquor at			
	Pri. Eff.	Ret. Sldg.	Inf.	1/3	2/3	Eff.
Orthophosphates (mg/l as P)						
Mean	5.3	27.6	27.2	13.3	2.2	.12
Min.	4.9	12.8	18.0	5.5	.03	.04
Max.	5.7	51.0	40.2	22.3	11.3	.48
Dissolved Oxygen (mg/l)						
Mean	--	--	0.4	0.9	1.6	2.9
Min.	--	--	0.1	0.5	0.6	0.6
Max.	--	--	0.7	3.5	4.2	6.0

The final clarifier contents were monitored for dissolved oxygen and the final effluent for orthophosphate during the study period. Dissolved oxygen concentrations ranged from 0.1 to 1 mg/l, averaged 0.4 mg/l in the final clarifier, and ranged from 0.1 to 0.2 mg/l in the return sludge. Orthophosphate concentrations in the final effluent ranged from .3 to 3.4 mg/l and were erratic from one clarifier to another. Release of orthophosphate from the sludge to the final effluent averaged 1.5 mg/l during these studies.

Sludge blanket depths could not be measured. The sludge usually extended throughout most of the clarifier depth with high prevailing sludge volume indices. The release of orthophosphate to the final effluent was attributed to the low dissolved oxygen environment and the long retention of return sludge in the final clarifiers.

The vehicle for disposal of the phosphorus is the wasting of the activated sludge as illustrated by the balance. Since phosphorus removal is not possible in a closed cycle system, neither the wasted sludge nor its phosphorus laden components can be returned to the activated sludge process. Detention of the sludge under anaerobic conditions results in phosphate release.

Excess sludge is removed by mixed liquor wasting and thickening. The thickened sludge is then digested and stored in lagoons. Samples were analyzed to measure the phosphorus content in this disposal train. The 26 analyses summarized below estimate the mean concentration of these disposal streams.

Waste Activated Sludge
Phosphate (mg/l as P)

<u>Waste ML Sludge</u>	<u>Thickener Overflow</u>	<u>Thickener Conc.</u>	<u>Digester Discharge</u>
<u>Total</u>	<u>Ortho</u>	<u>Total</u>	<u>Total</u>
150	1.5	3.1	180
		1,240	1,260

The overflow from the thickener, a component of the final effluent and a potential source of significant phosphate addition, had similar ortho and total phosphate concentrations; therefore, no reduction in removal efficiencies resulted.

Detention in Aeration Tanks and Final Clarifiers

The removal of phosphorus by the activated sludge process has been found time dependent.(2) The detention of both the mixed liquor in the aeration tank and the return sludge in the clarifier influences the phosphate removal efficiency, and dye tracer studies were conducted to measure their flow-through characteristics.

Rhodamine WT dye was added to an aeration tank at the head end of the second pass--the point of primary effluent inflow. Dye concentrations were monitored at the end of each of the three passes by means of a fluorometer until they returned to the background level. Dye accounted for in the tank effluent was within six percent of the amount added. Figure 3 shows dye dispersion curves at three locations in the tank. The 2.5 mg aeration tank with a length to width ratio of 25 to 1 had a 4.5-hour displacement time (t_d) under test conditions. The modal detention time (t_M) was 3.8 hours or 84 percent of t_d , indicating near plug flow hydraulics. Two percent of the flow received less than two hours of aeration, and 83 percent of the flow received greater than three hours of aeration.

Rhodamine WT dye was added to the inlet well of a final clarifier and monitored in the overflow and return sludge for 4.5 hours (Figure 4). The displacement time (t_d) of the clarifiers was 2.0 hours; however, the modal detention of the overflow was 0.5 hour or 25 percent of the t_d . The overflow dispersion curve approaches that of a complete mix basin with only 12 percent flow through occurring prior

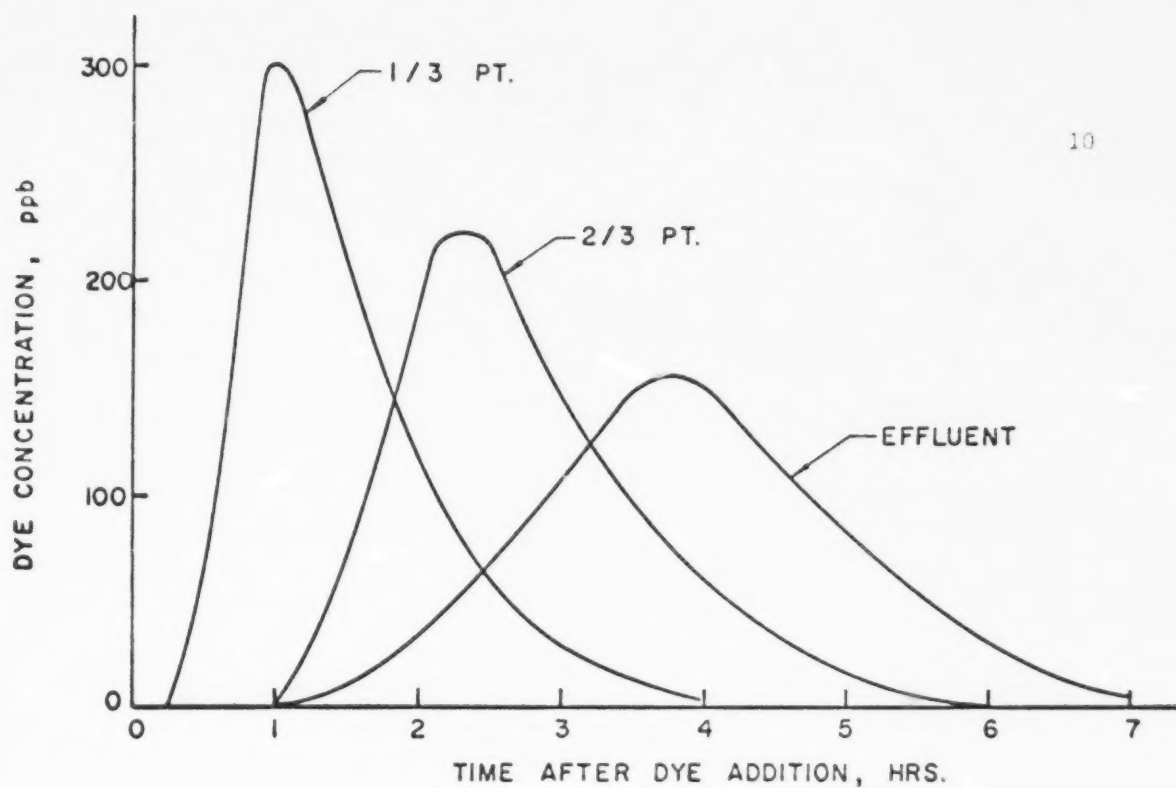


FIGURE 3

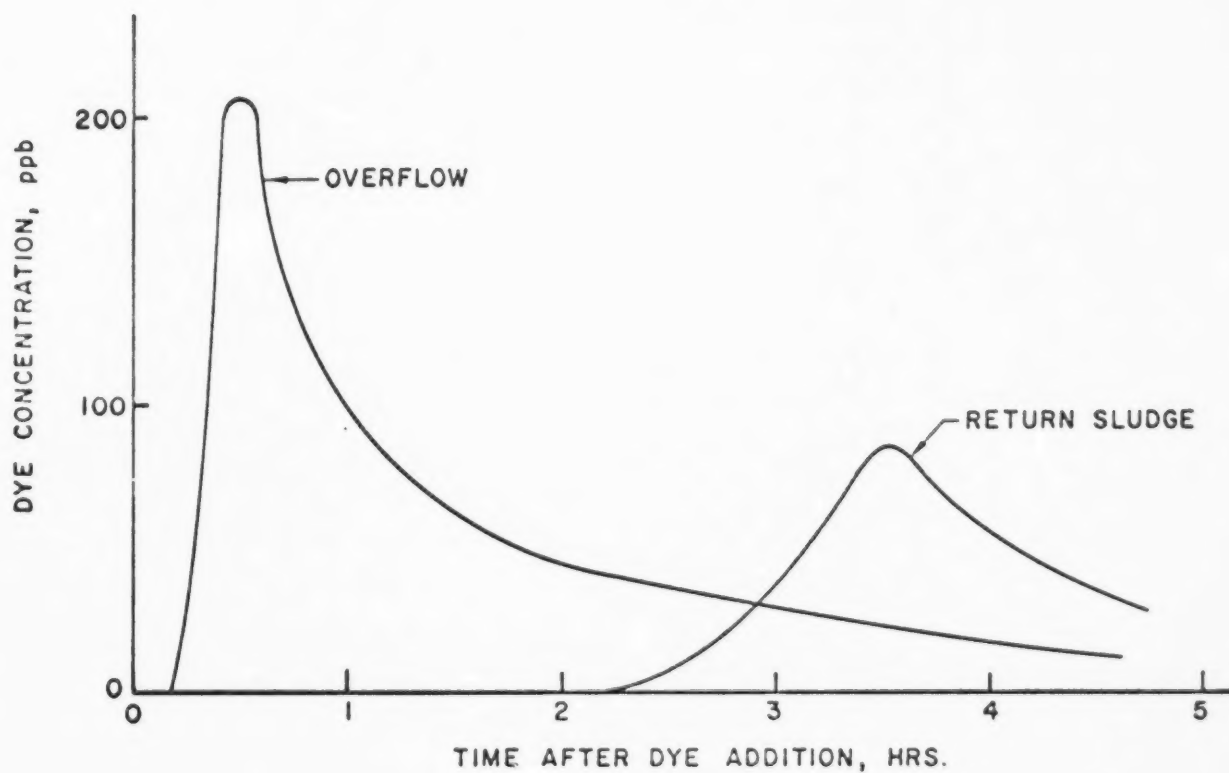


FIGURE 4

to the mode. The return sludge flow had a modal detention of 3.75 hours with the first traces of dye appearing at 2.0 hours. At the time of the study, the mixed liquor was not readily settleable, and a dispersed sludge blanket extended throughout most of the clarifier's depth.

Plant Comparison

Long-term phosphate removal efficiency of 80 percent has been reported at the Rilling Plant in San Antonio, Texas.(1)(2) Many of the design features and operating conditions at the Fort Worth Village Creek Plant are the same as those at the Rilling Plant; however, several major differences in the activated sludge process were observed.

Only the Fort Worth Plant had sludge reaeration which increased its sludge age to 12-day versus 3.2-day at the Rilling Plant. The BOD loading based on the inclusion of solids stored in the reaeration tank was 0.15 pound BOD per day per pound of suspended solids or one-third that in the Rilling Plant; however, considering only the solids in the mixed liquor, the loading was 0.35 lb./day/lb. MLSS or three-fourths that in the Rilling Plant. The Village Creek aeration tanks received a waste with 260 mg/l BOD versus 180 mg/l for the Rilling tanks.

The sludge settling characteristics were different with SVI values of 260 and 155 mg/l in the Village Creek and Rilling Plants, respectively. Distinct sludge blankets, 1 to 2 feet in depth, were measured in the Rilling final clarifiers while the dispersed sludge at the Village Creek Plant made measurement impractical.

Since both plants obtain high phosphorus removal, the inclusion of reaeration and the differences in sludge age, BOD loading, and BOD concentration are concluded to be within the limits of design and operation for high phosphate removal. The high SVI value and dispersed sludge resulted in unnecessary release of phosphorus to the final effluent.

In Summary

The activated sludge process removed 74 percent of the total phosphorus during the seven-day investigation. This was supported during 60 hours of intense monitoring when the process removed 76 percent of the orthophosphate. The total phosphorus removal was 83 percent in the combined primary and secondary treatment processes. Total and orthophosphate concentrations in the final effluent averaged 2.9 and 1.5 mg/l as P, respectively.

The removal of soluble phosphate in the aeration tanks averaged 98 percent; however, release from the sludge to the effluent in the final clarifiers lowered removal efficiencies. The release was attributed to sludge detention in excess of 2 hours and insufficient dissolved oxygen concentrations of 0.4 mg/l in the clarifiers. The released orthophosphate averaged 1.5 mg/l as P and constituted most of the phosphorus discharged to the stream.

The high removal in the aeration tanks was obtained under the following general conditions: mixed liquors of 2,500 mg/l suspended solids and 3.0 mg/l dissolved oxygen; loading of 0.35 pound of BOD per day per pound of suspended solids in the aeration tank; aeration of 83 percent of the mixed liquor for at least 3 hours; sludge reaeration displacement time of 5 to 6 hours; sludge age of 12 days; and wasting of the excess sludge without recycling the phosphorus.

Acknowledgment

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2. Priesing, C. P., J. L. Witherow, L. D. Lively, M. R. Scalf, B. L. DePrater, L. H. Myers, and J. A. Horn, "Phosphate Removal by Activated Sludge, Pilot and Plant Research," Federal Water Pollution Control Administration, Robert S. Kerr Water Research Center, Ada, Oklahoma. Presented October 11, 1967, New York Water Pollution Control Federation Meeting.